Use of Image Segmentation Algorithm to Test Model Spectral Distribution for Surgical Lighting

Maritoni Litorja
Physical Measurement Laboratory
NIST
Gaithersburg, MD
litorja@nist.gov

Daniel Samarov
Information Technology Laboratory
NIST
Gaithersburg, MD
samarov@nist.gov

***Abstract*—Lighting is an essential tool in surgery. Altering the spectral distribution of the lighting can heighten visual contrast between anatomical features of interest and the surrounding tissues. Due to the difficulty in assessing lighting spectral distributions on surgical scenes, we use image segmentation algorithm as a means of testing the relative merits of model spectral distribution for surgical lighting, compared to conventional surgical lighting. The relative accuracy in identifying the common bile duct (CBD), as known from the annotated collected hyperspectral images of surgical scenes, is used as a figure of merit to determine viability of lighting spectral models.**

***Index Terms*—surgical lighting, hyperspectral imaging, common bile duct, image segmentation**

I. Introduction

Lighting is an essential tool for the surgeon but its spectral properties are not particularly designed to be task-specific. Computing the optimum lighting spectral distribution to heighten visual contrast between a desired anatomical feature from surrounding tissue based on their intrinsic optical reflectance property is promising but needs to be tested. The testing can be done using human subjects viewing the same scene under the test lighting conditions. However, this is difficult because it is not feasible to reproduce a surgical scene to test the lighting; reproducing the tissue spectral reflectance properties using surrogate materials is also difficult. A method of testing the effectiveness of the model lighting distribution is through the use of image segmentation algorithms and comparing the feature identification accuracy when the intrinsic reflectance spectra are convolved with current typical spectral light distribution and that when the intrinsic reflectance spectra are convolved with the designed spectral lighting.

Identifying and locating the common bile duct (CBD) during cholecystectomies is important as injury to it can lead to serious and painful complications. One of the causes of misidentification or missing it is attributed to visual misperception. One way to augment the surgeon's vision to aid in identifying and locating the CBD is through enhancing the visual contrast between the CBD and the surrounding tissues. The CBD contains bile, which lends it a bluish-green hue. By adjusting the spectral distribution of the surgical lighting, it is feasible to heighten the contrast between the CBD and surrounding tissues. The use of lighting provides the surgeon an immediately accessible tool for feature discrimination, without having to rely on image acquisition and processing which is difficult in a temporally demanding application.

It should be noted that the intended technological product is task-specific lighting and *not* the image processing algorithm for identifying the CBD. The latter is merely used as a tool to check the feasibility of optimized lighting method for enhanced visual contrast, in lieu of testing with human subjects. It is cumbersome to create even an already designed lamp. Data that support its potential effectiveness as a surgical visualization tool would be highly beneficial.

II. Hyperspectral Image Data

The objective is to design task-specific lighting and we use previously collected image data in order to calculate the optimal lighting. Hyperspectral data over the human visual range (400 nm to 700 nm) of surgical scenes were collected using a NIST calibrated hyperspectral imager [1]. Hyperspectral imaging can yield useful information such as band-by-band images, but it is slow and expensive to implement for routine surgical work. The data collected were from open surgeries where the CBD (normal, not diseased) was exposed and annotated by the surgeon. Image data of a white reference plaque (99.9 % reflectance over the visual range) was also taken, which serves as the 'blank' by which the raw image is normalized against. The normalization procedure allows the spectra of the ambient lighting during the image collection to be taken out leaving the intrinsic scene reflectance data.

III. Prior Work on Image Data

Normalized hyperspectral images are valuable data sets for testing image processing algorithms. These surgical scenes were previously used to test robustness of image segmentation algorithm for discriminating the CBD within and between different data sets, using (annotated) CBD spectra from any one image on the other sets [1] since there are no "ground-truth" CBD spectra. While there are several data sets, we use only one as in the test here.

IV. Calculating Enhanced Contrast Lighting

The method of calculating optimum lighting spectral distribution to highlight the CBD has been described previously [2]. Briefly, the reflectance spectra of the CBD relative to surrounding tissues are reproduced from Ref 2 in Figure 1, along with the grayscale image and the screenshot during the hyperspectral data acquisition where the surgeon identifies the CBD structure.

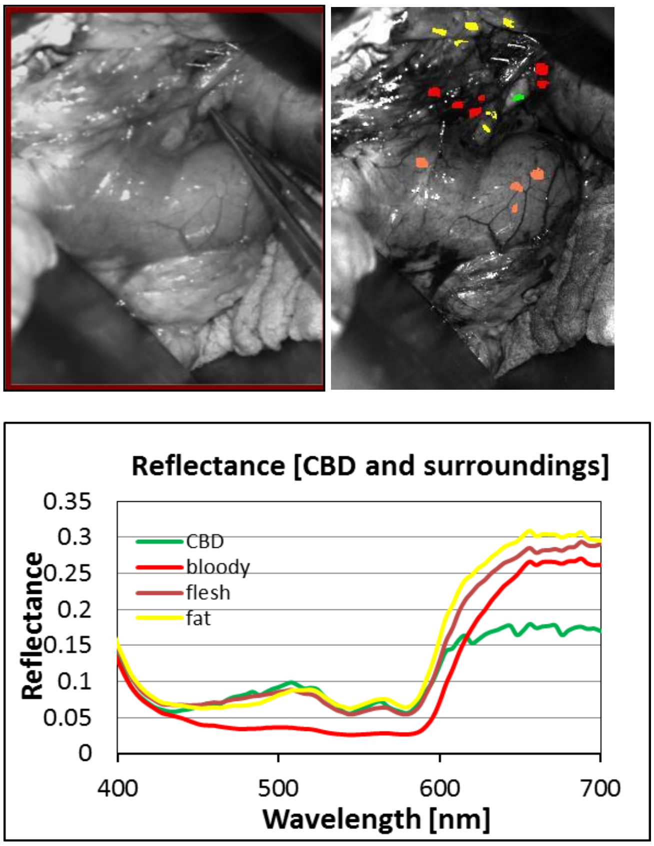

Figure 1. (Top left) Screenshot during hyperspectral image data acquisition where the surgeon points to the bile duct, (bottom) reflectance spectra of the regions of different types of tissues correlated to the colored areas in the grayscale image (top right).

Optimum lighting computation is based on maximizing the total color difference, ΔE*ab value, in the CIELAB colorspace [3] between two color stimuli. We use the NIST Color Quality Scale calculator to compute this value for hyperspectral image patches corresponding to the CBD and the surrounding tissues. NIST CQS is a spreadsheet tool designed for rating spectral lighting distributions for a variety of performance metrics including Color Rendering Index (CRI) [4,5]. A few lighting spectral distributions were tested to maximize the ΔE*ab value. Out of the few tested, the spectra in Figure 1 showed promising results in the ΔE*ab and is used as the model lighting in this test. The model lighting spectra have a peak at 490 nm corresponding to the blue-green region of the visual range. Also shown are the spectra of a D65 standard illuminant, common room lighting.

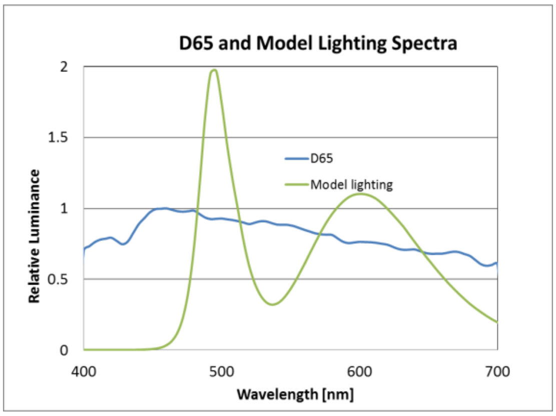

Figure 2. Spectra of D65 illuminant and the model lighting, of comparable total luminances.

We have previously used computationally re-lighted images to show image differences with different lighting. The computationally re-lighted image (Fig 3 right) is intended to show *how the scene would appear to the surgeon's eyes.*

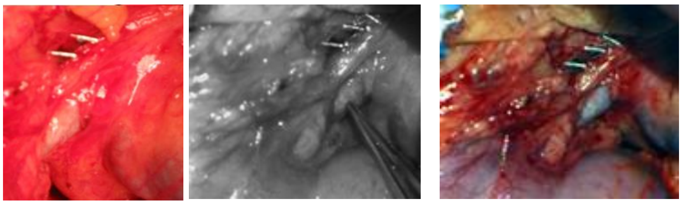

Figure 3. At left is a digital photograph of the scene showing the common bile duct. At center is a screenshot of the scene under 580 nm light during the hyperspectral image data collection with the surgeon's annotation. At right is the computationally 're-lighted' image from the hyperspectral data with the model lighting spectra shown in Fig. 2.

However, every color imaging software and every color presentation device has its own color management system, such that a computed 're-lighted' image such as the one shown above *may not be reliable.* A different approach to testing the comparative effectiveness of the light spectra is needed.

V. Results from Testing Lighting Effectiveness

The normalized hyperspectral image file is convolved with lighting spectra of interest and the human tristumulus values (xyz-bar). The resulting hypercube data is still hyperspectral, where each image pixel has a spectral profile over the visual range (400 to 700 nm). This is the file operated on by the image segmentation algorithm. The algorithm is described in detail in Ref. 1 and searches for spatial and spectral similarity in all pixels in the image to the CBD pixels identified by the surgeon as the basis. The algorithm has been shown to successfully identify the CBD, along with a few false-positive regions. While the previous work in Ref 1 used spectral *absorbance* of the tissue as the spectral profile for similarity matching, in this work we use the *reflectance* convolved with the lighting and the human tristimulus values. This is intended to be representative of what the human eye would see.

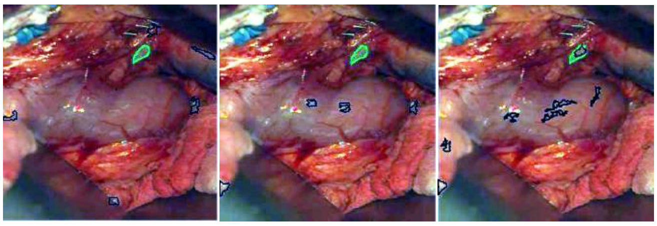

Figure 4. The green outlined region is the annotated CBD while the black outlined regions are the regions found by the algorithm as CBD. On the left is the normalized data only (no lighting), center is with D65 lighting and right is D65 with the model lighting designed to highlight the CBD. The true positive is only found when the model lighting is superimposed on the D65 lighting.

Results of the test using the image segmentation algorithm are shown on Figure 4. A search for regions with similar spatial and spectral shape to the CBD (true positive) over the whole image only yields false positives using the normalized data only (no lighting). When D65 spectra are applied, the search still yields only false positives, missing the true positive. When the model lighting is applied, along with the D65 room light, the search yields the true positive as well as a few false positives.

This is a highly promising result in that the model spectra, which is intended to highlight the CBD, does improve the search algorithm outcome. We can use the search algorithm and precision metrics (ratio of true positive to sum of true and false positive) to rate the relative performance of various model lighting. This is a quantitative approach and can save time and effort in finding the optimum spectral lighting distribution to highlight a desired anatomical feature that under normal room lighting offers little visual color difference. Such lighting is designed to augment the surgeon's vision for better feature discrimination.

REFERENCES

[1] D. Samarov, E. Wehner, R. Schwarz, K. Zuzak and E. Livingston "Hyperspectral Image Segmentation of the Common Bile Duct" Proc. SPIE 8618, 861806 (2013).

[2] M. Litorja, M. Fein, E. Wehner, R. Schwarz, K. Zuzak and E. Livingston, "Spectral light distribution variations to enhance discrimination of the common bile duct from surroundings in reflectance hyperspectral images" Proc. SPIE 8618, 861805, 2013.

[3] G. Wyszecki and W.S. Stiles, Color Science: Concepts and Methods, Quantitative Data and Formulae, 2nd ed NY:. Wiley and Sons, 1982, p.168

[4] Y. Ohno, Color Rendering and Luminous Efficacy of White LED Spectra, Proc., SPIE Fourth International Conference on Solid State lighting, Denver, CO, August 2004, 5530, 88-98 (2004).

[5] Y. Ohno, Simulation Analysis of White LED Spectra and Color Rendering, Proc., CIE Expert Symposium on LED Light Sources, June 2004, Tokyo Japan.